Primary Timing Reference Sources for IEEE-1588 Systems

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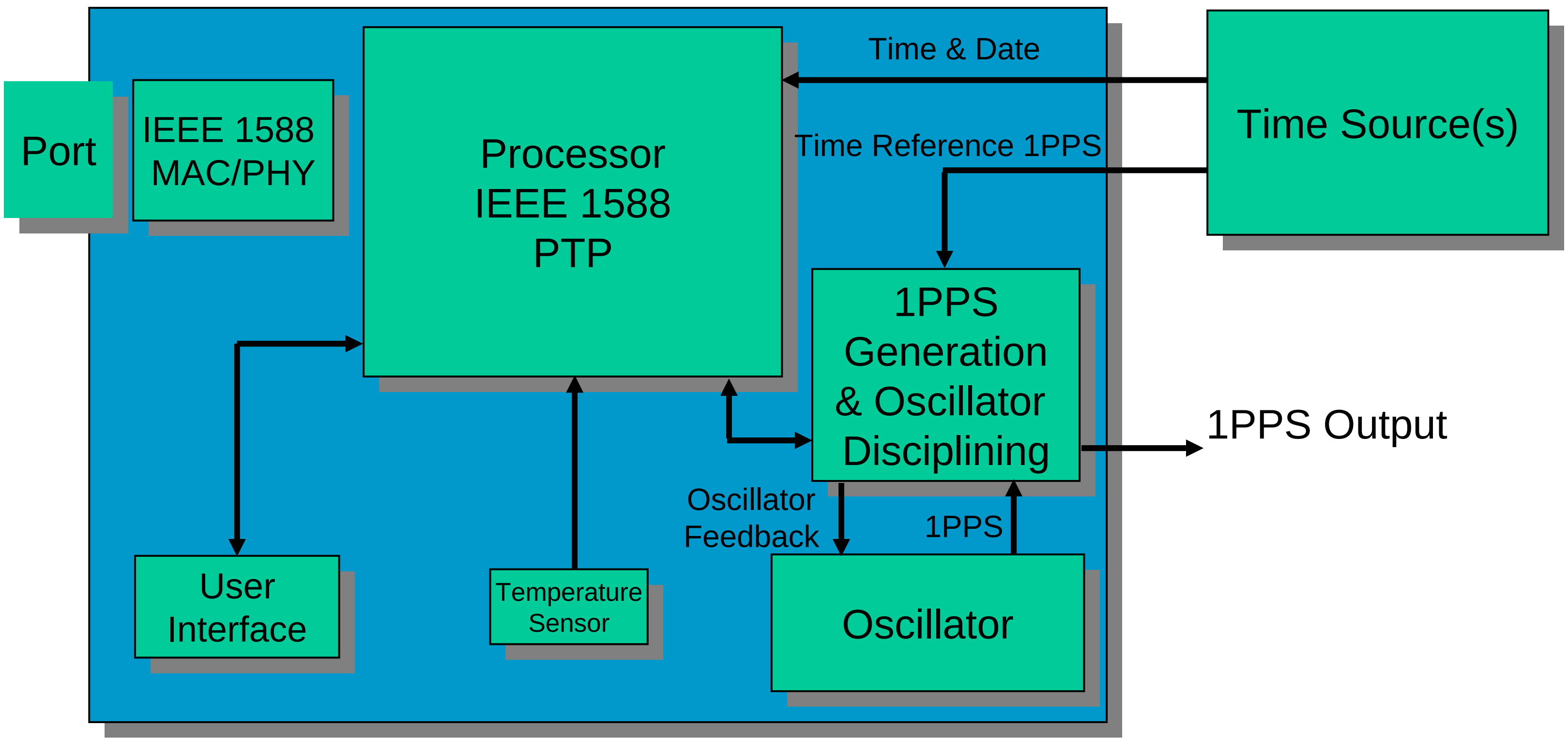
Master Clock Requirements

- IEEE 1588 Protocol Implementation
- Time Source
  - UTC Time Reference, or arbitrary user defined time base
  - 1 PPS or On Time Point input
  - May support an optional secondary Time Source
- Port to Physical Transport - e.g. Ethernet
- Oscillator
  - Meets minimum accuracy, stability, and adjustment range
  - Satisfies Holdover Time between max sync time interval
- 1PPS Output
- User Interface

Architecture of a Master Clock



Time Source Characteristics

- Time sources typically have two primary features
  - Delivery of current time
    - Current UTC, Local or arbitrary user defined time is delivered within a specified accuracy
  - On Time Point or 1PPS input
    - Many time delivery protocols provide a means to indicate that at a particular instant the current time data is valid. This is typically done by an On Time Point in a data stream or by a 1PPS input.

Time Sources

- Radio Clocks
  - Radio signals
    - US – (WWV, WWVB, WWVH), Germany-DCF77, UK-MSF, Japan-JJY, Canada-CHU, .etc
  - GPS, GLONASS, India's NPL INSAT
  - Loran, Enhanced Loran
  - Cellular Networks - GSM, CDMA
- Terrestrial Time Servers
  - Private and Public NTP Servers
  - NIST Services Dial Up (ACTS), Internet (ITS), and FMS
- External Interface to a Time Source
  - IRIG, RS-232, RS-422, RS-485, and E1/T1 (SDH)

Radio Signals as a Time Source

- Benefits
  - Supported by National Labs and Standards bodies
  - Broadcast is generally available across wide area
  - Antenna and sky view only is required
  - Typically has good long term stability/accuracy
- Drawback
  - Regionally available
  - Reception can vary due to atmospheric conditions and interference
  - Indoor reception can be difficult or poor
  - Radio Receiver for Time Source signals can be low cost or expensive for full NTP Time Server systems

GPS as a Time Source

- Benefits
  - GPS receiver cost is dropping and sensitivity increasing
  - Typical GPS Receiver is a very accurate/stable time source
  - Acts as a reference to an Atomic Clock Standard
  - Available worldwide
- Drawbacks
  - Dependent on US Military
    - Reception can be jammed & degraded
  - Antennas must have clear sky-view, doesn't work indoors
  - Not all GPS receivers are suitable for time sync
    - Poor stability and/or accuracy
    - Not all GPS receivers provide 1PPS

Loran as a Time Source

- Benefits
  - Available across large areas of land and sea
  - Accuracy and stability is similar to GPS
  - Ground wave signal is stable and easy to receive
  - Referenced to Atomic Clocks
  - Metrics and phase data available daily
- Drawbacks
  - Equipment cost can be higher than GPS systems
  - Reception is limited geographically
  - Long term future of Loran system is uncertain

GSM and CDMA as Time Sources

- Benefits
  - Typically slaved to GPS
  - Available anywhere GSM/CDMA reception works
  - Indoor reception possible
  - Provides a data link connection if needed
  - About the same cost as a GPS based solution
- Drawbacks
  - GSM and CDMA are only regionally available
  - Not all Cellular networks are synced to UTC
  - Does not provide a GPS independent backup
  - May not provide 1PPS input

NIST and NTP as Time Sources

- Benefits
  - Dial up and Internet NTP Servers are maintained by National Standards bodies
  - Reliable Modem backup to Internet and GPS
  - Low cost
- Drawbacks
  - Not as accurate as other sources
  - Subject to internet and telephony access risks
  - No 1PPS input for modem and internet interfaces

External Interfaces to Time Sources

- Benefits
  - Provides direct ‘foreign’ connection to external time source such as
    - Atomic Clock, GPS, Radio, GSM/CDMA, NTP Server, Loran, .etc
  - On Time Points of protocols can simulate 1PPS
- Drawbacks
  - Inputs could lack 1PPS input or On Time Point
  - High latency of some interfaces may require a lower Stratum level than the Time Source

What does Stratum mean?

- IEEE 1588
  - Indicates with Identifier time accuracy relative to UTC
  - Identifies whether a clock is a Primary, Secondary, or is not a Reference to a standardized source of time
- NTP
  - Stratum & Code indicate Reference status/source
    - 0 – Undefined, 1 – Primary, 2-255 – Secondary
    - Codes - e.g. NIST, ATOM, VLF, WWVB, LORC, GPS
- T1.101
  - Stratum indicates minimum accuracy of clocking
    - Stratum 1 - $<1x10^{-10}$, Stratum 2 – $<1.6x10^{-8}$, Stratum 3 - $<4.6x10^{-5}$, Stratum 4 - $<3.2x10^{-5}$

Stratum Numbers

Table 3—Stratum number definitions

Stratum number	Specification
0	May be used temporarily for special purposes by PTP implementations to force a clock to be deemed better than other clocks in the system.
1	Designates the clock as a primary reference standard traceable to a recognized standard source of time. A stratum 1 clock may be either a boundary clock or an ordinary clock. (NOTE—GPS clocks, calibrated atomic clocks, etc. fall into this stratum). A stratum 1 clock shall not be synchronized using the PTP protocol to another clock in a PTP system.
2	Designates the clock as a secondary standard reference clock. The clock shall be: — Directly (not via PTP) synchronized to a stratum 1 clock or another source deemed to be a correct source of time for the PTP subdomain or — Previously directly synchronized to a stratum 1 clock or another source deemed to be a correct source of time for the PTP subdomain and is still providing time information consistent with this clock or source as specified by the clock_identifier associated with the clock (see 6.2.4.5).
3	The lowest possible clock_stratum value if not 1 or 2 for a clock that is capable of issuing external timing signals and possibly setting the PTP_EXT_SYNC flag to TRUE (see 8.2.10).
4	The lowest possible clock_stratum value if not 1 or 2 for a clock that does not have the capability of issuing external timing signals and therefore sets the PTP_EXT_SYNC flag to FALSE (see 8.2.10).
5–254	Reserved.
255	The default value. A clock with this stratum number shall never be the best master clock.

Clock Identifiers

Table 4—Clock identifier definitions

Clock identifier (ASCII)	Applicable to clock_stratum number	Specification
ATOM	1	Time is derived from a calibrated atomic clock maintaining a UTC time base accurate to better than 25 ns
GPS	1	Time is derived from a correctly operating GPS receiver maintaining a UTC time base accurate to better than 100 ns.
ATOM	2	The stability of the clock is such that it is accurate to within 100 ns of the UTC time base established the last time it was synchronized directly to a stratum 1 clock with clock_identifier ATOM. A power cycle may preclude this designation.
GPS	2	The stability of the clock is such that it is accurate to within 100 ns of the UTC time base established the last time it was synchronized directly to a stratum 1 clock with clock_identifier GPS. A power cycle may preclude this designation.
NTP	2	The clock shall meet one of the following specifications: — The clock is correctly and actively participating in a suite of clocks using the NTP or equivalent protocol to maintain a UTC time base accurate to better than 15 ms, or — The stability of the clock is such that it is consistent to within 50ms of the time base established the last time it was correctly and actively participating in a suite of clocks using the NTP or equivalent protocol to maintain time consistent with UTC. A power cycle may preclude this designation. Examples of protocols providing time bases and accuracies equivalent to NTP are SNTP, link to NIST time server, etc.
HAND	2 or greater	The clock has been set to the correct UTC time to accuracy better than 10 seconds by an administrative procedure and is consistent with that time except for normal drift of this clock. A power cycle may preclude this designation.
INIT	2 or greater	The clock has been set with unspecified accuracy to an arbitrary or user-defined time by an administrative procedure and is consistent with that time except for normal drift of this clock. A power cycle may preclude this designation.
DFLT	3 or greater	Applicable if none of the other clock_identifiers apply.

Stratum Levels and Clock Identifiers

Identifier	Stratum	Specification	Time Source
ATOM	1	< 25 ns	UTC Atomic Clock
GPS	1	< 100 ns	GPS Receiver
ATOM	2	<100 ns	UTC Atomic Clock
GPS	2	< 100 ns	GPS Receiver
NTP	2	< 15 msec	NTP Server - Internet
NTP	2	< 50 msec	NTP Server - Dialup
HAND	>= 2	< 10 sec	Setting time manually, or automated
INIT	>= 2	Unspecified	User Defined
DFLT	>= 3	None	None

Stratum Levels and Clock Identifiers

Time Source	1PPS - Time Uncertainty	Frequency Uncertainty	Identifier	Stratum
Typical GPS Receiver	< 20 nsec	$< 1x10^{-12}$	GPS	1
GLONASS (and GPS)	20-500 nsec	10^{-9} to 10^{-13}	GPS	>= 1
INSAT	20 usec	$5x10^{-10}$	NTP	2
Loran, Enhanced Loran	<100 nsec	$1x10^{-12}$	GPS	>= 1
CDMA slaved to GPS	<10-100 usec	~GPS	NTP	2
GSM slaved to GPS	< 100 usec	~GPS	NTP	2
AMPS (Analog Cellular)	T1 or Local Clock	$\sim 1x10^{-9}$	>= INIT	>= 2
Un-synced Cellular Network	Undefined	Unknown	INIT	>= 2

Stratum Levels and Clock Identifiers

Time Source	1PPS - Time Uncertainty	Frequency Uncertainty	Identifier	Stratum
WWVB, DCF77	0.1-15 msec	10^{-10} to 10^{-12}	NTP	2
WWV, WWVH	1-20msec	10^{-6} to 10^{-9}	NTP	2
CHU (no path delay)	< 1 msec	< 10^{-4} sec	NTP	2
IRIG	20 - 200 usec	Varies	NTP	2
RS-232, RS-485	< 0.1 - 1 msec	Varies	NTP	2
T1.101 Stratum 1-4	See Stratum	3.2×10^{-5} to 1×10^{-11}	NTP	>= 2
NIST ACTS	< 15 msec	NA	>= NTP	2
NIST ITS	< 100 msec	NA	>= NTP	>= 2
NIST FMS	< 20 nsec	2×10^{-13} to 2×10^{-15}	ATOM	1

Oscillator Choices

- Quartz Crystals
  - Improvements include disciplined and temperature compensated crystals and PICO Ensembles of Quartz Oscillators nearing atomic clock performance
- TCXO
  - Improvements include Disciplined TCXO systems
- OCXO
  - Improvements include Disciplined OCXO systems
  - Sophisticated OCXO approaching Atomic clock performance
- Atomic
  - Rubidium, Cesium, Hydrogen-Maser

Why is Holdover important?

- Holdover
  - The ability of a synchronized IEEE 1588 clock to stay within it’s specification for Stratum and Identifier until the next synchronization message from it’s master clock or time source
    - Defines the maximum time until a Master Clock must lower it’s Stratum and Identifier if not receiving a sync from it’s time source(s)
    - Holdover requirements define accuracy requirements for clock’s oscillator
    - Determines Quality of Service from a Master Clock in cases of loss of time reference

Stratum Level versus Oscillators

Oscillator	Frequency Uncertainty	Identifier	Stratum	Error Offset to UTC	Holdover
Cesium	$<1x10^{-12}$ – $1x10^{-13}$	ATOM	1	< 25 nsec	6.94 – 69.4 hours
Cesium	$<1x10^{-12}$ – $1x10^{-13}$	ATOM	2	< 100 nsec	27.78 – 277.8 hours
Rubidium	$1x10^{-12}$	ATOM	1	< 25 nsec	6.94 hours
Rubidium	$1x10^{-12}$	ATOM	2	< 100 nsec	27.78 hours
OCXO	$1x10^{-8}$ – $1x10^{-10}$	GPS	1, 2	< 100 nsec	10 - 1000 seconds
TCXO	$1x10^{-6}$	GPS	1, 2	< 100 nsec	0.1 seconds

Stratum Level versus Oscillators (2)

Oscillator	Frequency Uncertainty	Identifier	Stratum	Error Offset to UTC	Holdover
OCXO	$1x10^{-8}$ – $1x10^{-10}$	NTP	2	< 15 msec	17.36 - 1736 days
OCXO	$1x10^{-8}$ – $1x10^{-10}$	NTP	2	< 50 msec	57.87 - 5787 days
TCXO	$1x10^{-6}$	NTP	2	< 15 msec	4.17 hours
TCXO	$1x10^{-6}$	NTP	2	< 50 msec	13.9 hours
Quartz	$1x10^{-4}$ – $1x10^{-5}$	NTP	2	< 15 msec	2.5 – 25 seconds
Quartz	$1x10^{-4}$ – $1x10^{-5}$	NTP	2	< 50 msec	8.33 – 83.3 seconds
Quartz	$1x10^{-4}$ – $1x10^{-5}$	Hand	>= 2	< 10 sec	1.157 – 11.57 days

Summary

- GPS Time Sources are preferred, but others like Loran and GSM/CDMA have similar precision
- Alternate Time Sources which provide 1PPS or an On Time Point in the interface are preferred
- Utilize a backup Time Source to provide redundancy and independence from GPS
- Choose secondary time source such that your system can still function as a master clock in your application
- Design Master Clocks utilizing an oscillator with properties sufficient for your precision, accuracy and holdover requirements

Suggestions?

- Internationalization
  - might be easier if Unicode and a Language ID is used for Strings
- Clock Identifiers
  - Would more Identifiers for different time sources be useful?
- Additional Data Sets?
  - Would Time Source manufacturer & capabilities be useful?
  - Would Vendors specific datasets be useful?
  - Would listing of all time sources and priority be useful?

References

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